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Factsheet

Forced-Air Rapid Cooling of Fresh Ontario Fruits and Vegetables

Hugh W. Fraser, Resources Management Branch

Why is Cooling Important?

All fresh horticultural crops are living organisms, even after harvest, and they must remain alive and healthy until they are either processed or consumed. The energy needed to carry on living comes from the food reserves in the product itself. The process by which these reserves are converted into energy is called **respiration**. Some excess energy in the form of heat is released during respiration. This heat varies with the type of product, the variety, the level of maturity, amount of injuries, and the temperature. Since the final result of respiratory activity is deterioration and senescence, it makes sense to attempt to minimize the respiratory activity of freshly picked products.

The product **temperature** has the greatest influence on the degree of respiratory activity. Prompt, rapid, uniform cooling after harvest to remove **field heat** is therefore critical to lowering the rate of deterioration and increasing the product's shelf-life. Lowering the product's temperature also reduces the rate of:

(a) ethylene production and the sensitivity of products to ethylene;
(b) water loss and subsequent shrinkage;
(c) growth and spread of microorganisms;
(d) product response to injuries.

What is Forced-Air Rapid Cooling?

Forced-air rapid cooling is just one method of quickly removing the field heat from freshly picked produce. This system has been used extensively in California for many years. Growers there realized the benefits of quickly removing field heat, as shipping to distant destinations required a long product shelf-life. Experimentation with forced-air cooling included many products, as it was less expensive (compared to hydro-cooling with cold water), quicker (compared to conventional room cooling), and adaptable to many different products.

In Ontario, forced-air cooling is not as common and is presently being used on only a few dozen farms for strawberries (see Figure 1), peaches, and mushrooms. However, other Ontario products could benefit from this cooling method.

Forced-air cooling uses fans to pull refrigerated air through container vents and around the product inside the package. "Pulling" air through the containers rather than "blowing" it, is a better option as it is much easier to minimize "short-circuiting" (refrigerated air that flows directly to the fan without first going around the product) when the containers are under vacuum. The object is to force air to travel around the product. Rapid cooling ensues as a result of the intimate contact between cold air and the warm product. With proper container design, fast uniform product cooling can be achieved in baskets, boxes, bins, or bags.

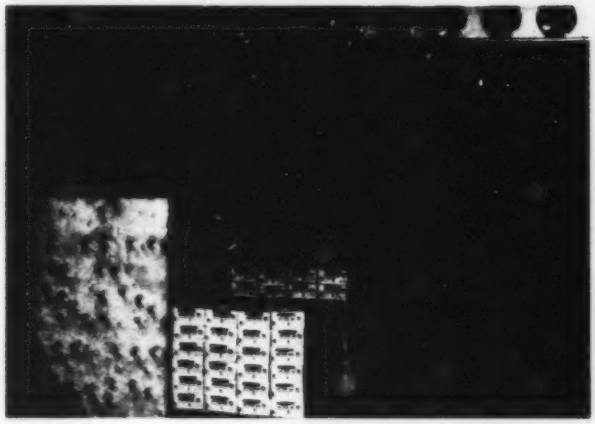

Figure 1 Forced-air cooler for strawberries (Courtesy: Joe Wismer, Jordan Station)

Forced-air cooling should not be confused with room cooling. In room cooling, refrigerated air is simply circulated around the room. Air takes the path of least resistance, so there is no incentive for air to enter the containers and cool the hot product. Hence, the product cools mostly by **conduction**, a very slow process.

On the other hand, forced-air cooling enables refrigerated air to enter into containers because of a vacuum created by high capacity fans. The product cools as a result of the **convective** action of refrigerated air sweeping away hot air.

In tests done in Vineland in 1991, forced-air cooling was compared to room cooling of a pallet of strawberries. Temperatures in the center of the pallet were monitored over time. Forced-air cooling took about 1.25 hours to cool berries from 20°C to 2°C (68°F to 36°F) in the center of

the pallet (7/8 of the "field heat" removed), while room cooling took 3.75 hours just to cool the berries to about 14°C (57°F) in the same pallet location (1/4 of the "field heat" removed)! The time to reach "7/8 cool" in the room cooling method, was calculated to be about 27 hours or 21 times as long as forced-air cooling!

What Products Can Be Forced-Air Cooled?

It had traditionally been considered that products that dry out easily could not be force-air cooled. These included: lettuce, spinach and mushrooms that were generally vacuum cooled (this cooling method lowers the boiling point of water to 0°C (32°F) using a vacuum chamber); broccoli and sweet corn that were hydro-cooled and top-iced; and asparagus and peaches that were hydro-cooled. However, there have been successful attempts in forced-air cooling of these products as well, provided cooling is rapid and high humidity air is used. (See OMAF Factsheet *Humidity in Refrigerated Storages for Fruits and Vegetables*, Agdex 202/736).

Table 1 lists typical Ontario fresh fruit and vegetable temperatures at harvest, their recommended holding temperatures, and heat of respiration rates at various temperatures. Harvest temperatures can vary widely depending on the time of day and whether the fruit is in the sun or not. Tests on strawberries in the Vineland area in June 1991 showed strawberry temperatures in the sun of over 40°C (104°F) while still on the vine!

The higher the heat given off during respiration, the more susceptible a product is to deterioration. Note how much lower the respiration rates are at the recommended holding temperatures. For products such as berries, asparagus, mushrooms, broccoli, and corn, cooling should commence immediately after harvest and be completed within a few hours.

How Is Forced-Air Cooling Accomplished?

Forced-air systems can vary from a simple fan and box assembly that draws air horizontally through a couple of pallets of strawberry masters (see Figure 1), to elaborate separate forced-air cooling rooms with sophisticated controls. However, all systems (see Figure 2) require the same basic components consisting of:

(a) vented "in-line" containers;
(b) proper type and size of fans;
(c) an air ducting system (for cold/warm air);
(d) a method to control air short-circuiting;
(e) a monitoring system;
(f) adequate refrigeration system.

a) *Vented "In-Line" Containers*

Properly sized and located container vents is one of the most important criteria for quick cooling. Refrigerated air is generally drawn horizontally through the containers, although systems can be designed to draw the air vertically if necessary. The air **must** come in contact with as much of the product as possible, requiring containers with at least 5 to 10% of their sides vented for the air to both enter and exit. Ideally, this vented area should be distributed across the air entrance face of the container. Figure 3 shows some examples of the differences in venting between 4 types of 8

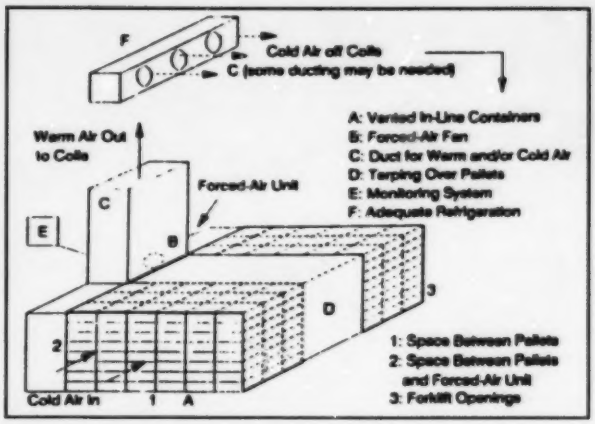

Figure 2 Components of a forced-air cooler and locations to check for air short-circulating.

quart strawberry masters. Note the wide range in their respective venting area percentages.

The location of the vented areas is important for uniform cooling. For example, in Figure 3, note the difference in side vent **locations**. The container on the bottom has 3% venting, with limited areas for air travel. The next one up has enough venting at 7.5%, but it is all at the top of the container. Product at the bottom of the quart containers could cool more slowly, resulting in uneven cooling.

The top two containers have sufficient venting area that is evenly distributed. There are vents at the top to cool the top fruit, and bottom vents that line up with corresponding vents in the quart containers. Fruit in these containers would cool more quickly and uniformly.

Most Ontario containers do not have sufficient or properly located venting to allow forced-air cooling. Vents have a big impact on a container's strength, so proper planning with the container manufacturer is important.

The cooling speed is enhanced if the vents line-up with each other when the containers are stacked on pallets. Containers such as berry masters are all stacked the same way on a pallet (see Figure 1), so that air can travel

Figure 3 Venting percentages of different strawberry masters.

horizontally in a straight line through the vents. Unfortunately, because of the dimensions of many Ontario containers and the way they are often cross-stacked on pallets, locating container vents which line up is virtually impossible.

For ideal forced-air cooling where there is cross-stacking on pallets, containers should be 50% longer than they are wide, with side and end vents that will line up when cross-stacked. Figure 4 shows a pallet of some cabbage containers that are stacked in 2 directions to accommodate the pallet dimensions. These containers are approximately 600 mm long and 400 mm wide (24 in x 16 in), or 50% longer than they are wide. The lower level shows the usual containers with few vents, none lining up on the pallet. The upper level has containers that have been "modified" to demonstrate how a redesign can accommodate more vents that line up regardless of their orientation on the pallet. Product in these containers would cool more quickly. Unfortunately, there are a limited number of containers available with these ideal dimensions. Growers that are concerned about the dimensions and venting of their containers should discuss the matter with their suppliers.

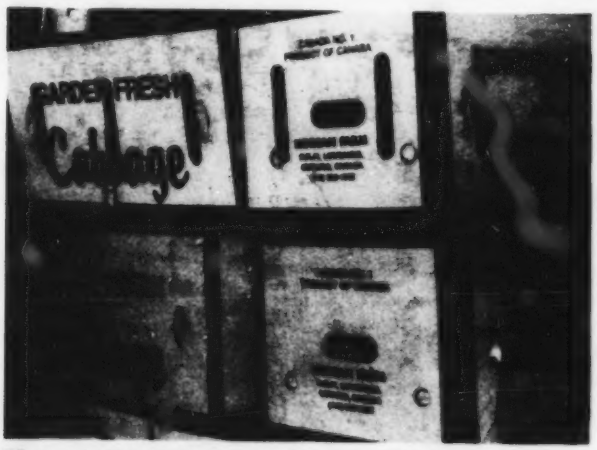

Figure 4 Comparison showing non-vented versus vented cabbage containers on a pallet.
(Courtesy: Sean Han, Lowbanks)

(b) *Fan Type and Size*

The higher the airflow rates, the quicker the cooling. However, fixed and operating costs of both the forced-air cooling system and the room refrigeration system can escalate as airflows are increased. Larger fans cost more to purchase and operate, and large motors add a considerable amount of heat to the cold storage room which must be removed. Ideally, fans are sized to provide between 0.5 to 3 litres of air per second (L/s) per kilogram of product being cooled (0.5 to 3 ft^3/min/lb). Sometimes large operations have to compromise on cooling speed by using lower airflows simply because of the high cost of providing high airflows for large volumes of product.

Depending on how much air is drawn through the product and how difficult it is to accomplish (resistance to airflow that the fan experiences), the static pressure drop across the air path through the product usually ranges from about 3 to 25 mm of water gauge (0.125 in - 1 in), with 12 mm (0.5 in) being typical.

For example, with the same airflow rates, it is more difficult to draw air through sweet corn in a bin than it is to draw it through melons in the same sized bin. This is because there is a difference in the amount of air spaces between the product. Centrifugal, or "squirrel-cage" fans are used since they are designed to withstand higher static pressures.

Suppose a forced-air system (see Figure 1) was designed to cool 2 pallets of strawberry masters with 64 masters per pallet. Assuming 5.7 kg (12.5 lbs) of berries per master, this is 730 kg (1600 lbs) of berries. Using 2 L/s/kg of air (1.9 ft^3/min/lb), the fan would be sized to deliver about 1460 L/s (3100 ft^3/min) of air at a static pressure of about 12 mm (0.5 in). This design would require a 0.75 kW (1 hp) belt-driven centrifugal fan, which costs approximately $500 (1991).

Some growers have attempted to use the fans on the refrigeration system's evaporator equipment to draw air directly through the product and into the cooling coils. This is not recommended, since these fans are not designed to handle higher static pressures of 12 mm water gauge (0.5 in.) or more.

(c) *Air Ducting System*

An air ducting system is needed to:

(a) deliver the refrigerated air from the evaporator's cooling coils to the product;
(b) direct the warmed air from the product to the forced-air fan and to the evaporator coils.

This ducting can often be provided using a combination of plywood and/or plastic tunnels. In simple designs (Figure 1) there are no air ducts, however in larger systems (Figure 2) they are more necessary. All ducts must be designed large enough in cross-section to minimize any extra resistance on the fans. A Consulting Engineer may be required to help in complicated situations.

(d) *Controlling Short-Circuiting of Air*

One of the most important but often most difficult requirements of forced-air cooling is to stop the short-circuiting of air. Air will always take the path of least resistance, so cracks must be plugged. Large plastic or canvas tarps are usually pulled over the containers to help force air to travel in one direction through the product. Common problem areas to check are: (1) between pallets; (2) between the pallets and the forced-air fan unit; and (3) at forklift openings. (see Figure 2).

By using a $50 static pressure gauge, one can see how plugging up cracks is effective. The gauge will monitor the pressure difference between cold air in the room, and warmed air just before it reaches the forced-air fan. A coloured fluid rises in a slanted glass tube (Figure 5) when the static pressure rises.

For instance, with the forced-air cooling fan running, but before the tarp is pulled over the pallets, the static pressure difference (a, b and c on Figure 5) would be 0 mm (0 in). After pulling the tarp over them, this difference may increase to 8 mm (0.3 in). Finally, if there were short-circuiting areas to seal up, the static pressure difference might rise to 12 mm (0.5 in). That is, the fan is working

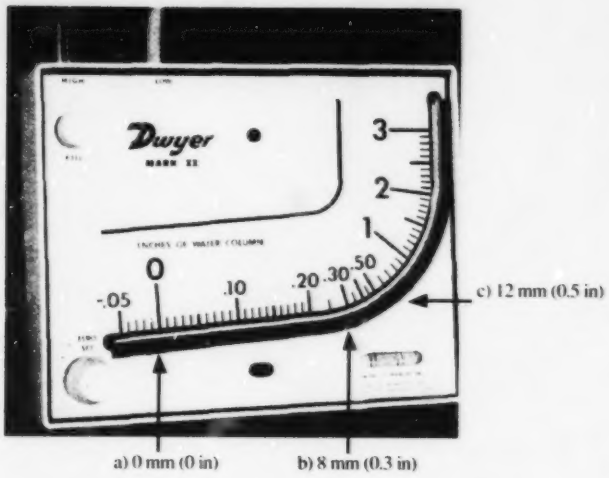

Figure 5 Static pressure gauge.

harder to get the air through the stack. Growers can check for short-circuiting by using cellophane or tissue paper to see where it is drawn in by the airflows.

For baskets, or other containers that have a lot of opening above the fruit, air can simply pass over the fruit very easily and there may be very little static pressure against the fan. In this case, the result could be that air simply short-circuits near the fan, with fruit further away not receiving as much air. An air tunnel system that limits the cross sectional area above the fruit may be required. In this way airflow is somewhat restricted and compelled to flow more evenly over all the baskets. It is beyond the scope of this Factsheet to discuss the design of this restricting system.

(e) *Monitoring System*

Both the **time** on the forced-air cooler and **product temperatures** should be monitored. This is especially important when the system is first used. After several uses most operators become familiar with the speed of cooling and the limitations of their equipment, depending on the temperatures of the incoming product and the room air, and the amount of product being cooled. Storage operators should use temperature probes with digital readouts that allow quick, accurate checks on product temperatures. Several locations should be checked to be certain that cooling is proceeding uniformly.

Constant monitoring of the air temperatures both entering the product and leaving the fan is one method of establishing the speed of cooling. Thermostats and/or timers can be devised that automatically shut off the forced-air cooling fans when the exiting air meets some set temperature or set time requirement. This allows unattended forced-air cooling.

(f) *Refrigeration System*

Forced-air cooling requires more refrigeration capacity since heat is removed much more rapidly. For instance, 2 pallets of strawberries weighing 730 kg (1600 lbs) that were normally cooled from 30°C to 2°C (86°F to 36°F) in 12 hours overnight might have required about 1800 W (6150 Btu/hr or 0.5 tons) heat removal capacity (excluding heat gains from the building and other sources). Cooling this same weight of product in only 2 hours would require up to 6 times as much refrigeration capacity. Storages with insufficient cooling capacity will rise in temperature and cooling will be prolonged. Also, other produce in the room may rise in temperature, since the room temperature may have increased.

Fan motors give off heat that must be removed by the refrigeration system. For example, adding a 750 W (1 hp) forced-air cooling fan will itself require an additional 865 W (2950 Btu/hr or 0.25 tons) of refrigeration.

Other Considerations

There are progressively more Ontario fruit and vegetable growers implementing forced-air cooling with a variety of methods. However, the objective is the same: to ensure that refrigerated air circulates where you want it to, so that **field heat is removed quickly and evenly without drying out the product.**

Table 1: Approximate Rates of Heat Evolution During Respiration at Various Product Temperatures for Some Ontario Fresh Fruits and Vegetables

	Harvest Temperatures	Holding Temperature[1]	Approximate Heat of Respiration at Various Temperatures[1,2,3] J/(kg.h)		
	°C	°C	0°C	15°C	25°C
*Apples (early)	15-30	0	40	290	425
*Asparagus	10-25	0	585	1950	4500
Blueberries	15-30	0	95	390	1100
*Broccoli	15-30	0	215	2450	7700
Cabbage (early)	15-30	0	60	240	600
Cantaloupes	15-30	0-7	60	385	710
Cauliflower	5-20	0	190	490	1200
Cherries (sweet)	15-30	0	50	375	500
*Corn (with husks	15-30	0	440	1740	3825
Grapes (Vinifera)	10-25	0	20	115	295
Honeydew Melons	15-30	7-10	-	150	325
*Lettuce (head)	15-30	0	120	410	875
*Lettuce (leaf)	10-30	0	250	670	1560
Mushrooms	17-20	0	340	2050	3500
Peaches	15-30	0	55	400	1100
Pears (Bartlett)	10-25	-1	25	130	525
Peppers	15-30	7-10	-	415	600
Plums	15-30	0	25	130	525
Raspberries	15-30	0	230	980	2300
*Spinach	10-30	0	220	1900	2700
Strawberries	15-30	0	160	870	2020
Tomatoes (ripe)	15-30	10	-	285	455

* *Less commonly forced-air cooled or more on-farm testing is needed.*

1. *Agriculture Canada Publication 1532/E, Commercial Storage of Fruits and Vegetables, 1988.*
2. *Agriculture Canada Publication 1822E, Canadian Farm Buildings Handbook, 1988.*
3. *USDA Handbook 66, The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks, 1968.*

The above values are averages and estimates from the various sources listed above and should be used for comparisons only.

To obtain imperial measurements: $^{0}F = (^{0}C \times 9/5) + 32$
Btu/(lb.h) = J/(kg.h)/2330

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